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THE 40-FOOT SOLAR ECLIPSE CAMERA OF THE LICK OBSERVATORY

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Abstract: The primary goal of the Lick Observatory's direct solar eclipse photography program was to secure high-resolution images of inner coronal structure and images in which coronal brightness could be studied. Between 1889 and 1932 the Observatory sent out seventeen eclipse expeditions worldwide. During these expeditions, direct coronal photography was a significant part of the program for the first couple of decades. By the end of the expedition series, spectrographic observations became of primary importance, yet direct coronal imaging continued.

Lick Observatory astronomer, John M. Schaeberle, conceived and constructed a large portable camera of 5-inch aperture with a focal length of 40-feet, and from 1893 the so-called 'Schaeberle Camera' became a hallmark of the Observatory's eclipse expeditions. In this paper we provide details of the Schaeberle Camera's design, setup and operation, and we briefly discuss some of the ways in which Lick Observatory staff and other astronomers used the plates obtained during the various eclipse expeditions in their investigations of the solar corona.

Keywords: Lick Observatory, John M. Schaeberle, Edward S. Holden, William W. Campbell, solar corona, solar eclipse expeditions, Schaeberle Camera

1 INTRODUCTION

During the nineteenth century knowledge of the solar corona, which could only be seen during a total eclipse of the Sun, developed rather slowly due to the rarity of viewable eclipses. According to Lick Observatory's W.W. Cambell (1923), a typical astronomer would only be able to observe a little over one hour of totality in a lifetime! Until the latter part of the nineteenth century drawing was the dominate method to make permanent records of a solar eclipse. During this period, astronomers began to use photography to generate permanent records that could be subjected to latter analysis. The first successful coronal images were obtained by Father Secchi and Warren De La Rue in 1860, from two different observing sites (Clerke, 1908; Pang, 2002; Proctor, 1871; Ranyard, 1879). While coronal imaging slowly improved as photography evolved from wet plates to the more sensitive dry-plate process, it was the Lick Observatory's first eclipse expedition, in January 1889, that set a new standard for producing high-resolution coronal images.

In 1873 the ailing entrepreneur James Lick decided to fund an observatory that would "… rank first in the world." (Wright, 2003: 13), and as a personal monument to himself Lick commissioned what was to be the world's largest refracting telescope, with a 36-inch objective. The giant telescope saw first light in 1888, and the fledging Lick Observatory (henceforth LO) was turned over to the University of California (henceforth UC). Edward S. Holden was appointed inaugural Director of the Observatory, and his special talent lay in raising funds from private sources (Osterbrock et al., 1988). He quickly convinced San Francisco banker and UC Regent, Charles F. Crocker, to provide funding for solar research and the Observatory's solar eclipse expeditions were named in his honour.

The Observatory's very first expedition was to Bartlett Springs (California) for the eclipse of 1 January 1889 (see Figure 1), and fine images of the inner corona were obtained by Staff Astronomer Edward E. Barnard with the Clark & Sons 'water reservoir' telescope (Barnard, 1889).[1] It is noteworthy that Barnard's best images gave more coronal detail than the images brought home by the well-equipped Harvard College party under W.H. Pickering (see Holden, 1889a, 1889b; Holden et al., 1889).

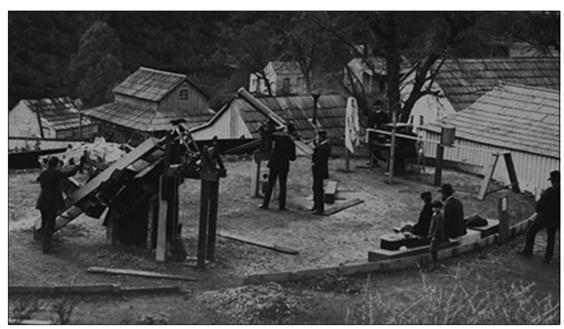

Figure 1: The Lick party at Bartlett Springs (Mary Lea Shane Archives).

2 JOHN M. SCHAEBERLE

One of those who was involved in preparing for Lick Observatory's second solar eclipse expedition was Staff Astronomer, John M. Schaeberle. Schaeberle emigrated from Germany in 1853, and his early life was spent in Ann Arbor (Michigan) where he broadend his background in a number of ways that would later make him an accomplished astronomer. After spending three years as a machine shop apprentice he studied astronomy and mathematics at the University of Michigan. In 1876 he was appointed an Assistant at the University's observatory, later becoming an Instructor of Astronomy and an Acting Professor. He was an avid telescope-maker and constructed a number of reflecting telescopes. In 1888, Schaeberle joined the staff of the Lick Observatory (Hussey, 1924).

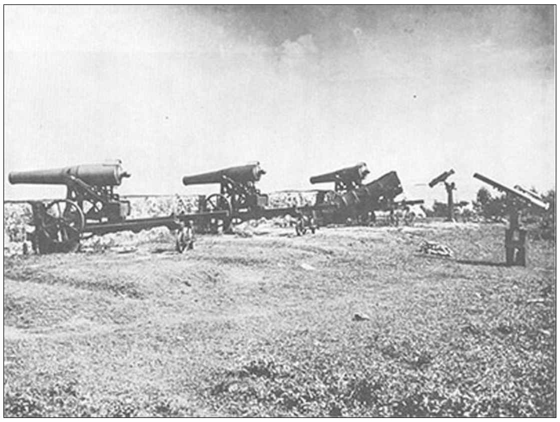

Figure 2: The battery site with Schaeberle's 18-inch reflector astride one of the cannon carriages, center-back of image (Mary Lea Shane Archives).

Schaeberle became Acting Director of the Observatory after Holden was forced to resign, his appointment becoming effective on 1 January 1898 (Osterbrock et al., 1988: 105-107), but he only served in this new capacity for four months, before being replaced by J.E. Keeler. As he was in charge of the Observatory during the January 1898 eclipse, Schaeberle asked W.W. Campbell to lead the expedition and conduct the research program designed by Holden (1897), who wished to determine whether the corona rotated with the Sun.

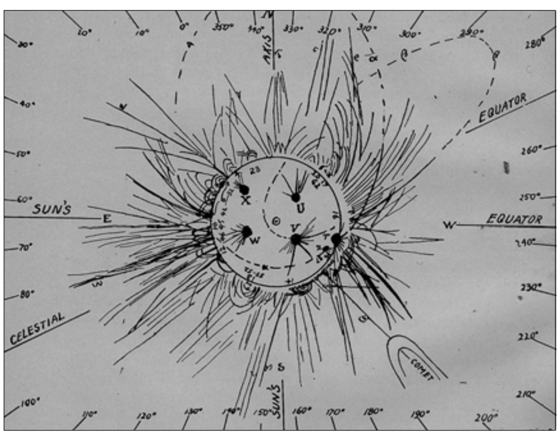

Figure 3: Skeleton drawing of a model showing the paths of ejected matter from the Sun's surface (after Schaberle, 1895: Plate 9).

After Keeler took over the Directorship of the Observatory Schaeberle was able to work closely with Barnard preparing a fully photographic program for the 21-22 December 1889 eclipse expedition to Cayenne, French Guiana (see Figure 2). Staff Astronomer S.W. Burnham joined Schaeberle on the expedition (Osterbrock *et al.*, 1988), and they used an 18-inch Newtonian telescope made from barrel hoops and packing crate wood with a mirror figured by Schaeberle to obtain eleven large-scale eclipse images (Holden, 1891a). When Holden reviewed the badly-overexposed plates and heard of the lack of success from the other expeditions, he proclaimed:

> The Lick Observatory expedition succeeded while NO other expedition (as I know) <u>has</u> succeeded at all. These twelve photographs will be the data on which *all the world* will have to depend. It is a great *credit* to America, to the state, and to the Lick Observatory. Burnham and Schaeberle have no superiors … *The English astronomers, I see, are doubting the reality of the extensions of the corona first photographed*. There is no doubt, *really*, for I found it on photographs taken from different places and our eye drawings. (Holden, 1890a; his underlining and italics).

The overexposure of the plates was a direct result of Holden's inflexible expedition directives (Holden, 1889c; 1890b). Making working conditions even more difficult, long argument was to ensue over the unstable Carcel lamp that was used to standardize the plates for photometry (Holden, 1890c).

Homeward bound from the December 1889 eclipse, Schaeberle laid the groundwork for a new theory to explain the intricate coronal features that he recorded in drawings and on photographs (e.g. see Figure 3). However, this was to be a momentary 'diversion', for he grew increasingly disillusioned at being passed over for the Directorship, and he eventually decided to leave the Observatory. He then began traveling internationally, with no immediate plans to return to astronomy. Nonetheless, he was again considered for the Lick Directorship in 1900, following Keeler's sudden death, but W.W. Campbell was appointed to the post (Osterbrock et al., 1988).

3 SCHAEBERLE'S MECHANICAL THEORY OF THE SOLAR CORONA AND THE DEMAND FOR A NEW TYPE OF ECLIPSE CAMERA

Schaeberle (1890: 68) first outlined his theory in a brief paper that appeared in the *Publications of the Astronomical Society of the Pacific*, where he stated that

> … his investigations seemed to prove conclusively that the solar corona is caused by light emitted and reflected from streams of matter ejected from the sun, by forces which, in general, act along lines normal to the surface of the sun; these forces are most active near the centre of each sun-spot zone ...
>
> The variations in the type of the corona [from eclipse to eclipse] admit of an exceedingly simple explanation, being due to nothing more than the change in the position of the observer with reference to the plane of the sun's equator …
>
> Mr. SCHAEBERLE … stated that he had thus far been unable to find a single observed phenomenon which could not be accounted for by his mechanical theory.

Further details appear in a second paper published the following year (Schaeberle, 1891).

The passage of time would show Schaeberle's mechanical theory to be flawed (especially when Hale was able to demonstrate the critical role of the Sun's magnetic field), but in the interim it inspired the design and construction of a new type of camera capable of providing the Lick astronomers with large solar images that would reveal fine coronal structure.

4 THE 40-FOOT SCHAEBERLE ECLIPSE CAMERA

Schaeberle (1895) designed a direct-imaging camera in place of the horizontal heliograph favored by other solar researchers, reasoning that the additional optical surfaces of a horizontal heliograph would degrade the quality of the image due to heat expansion issues. Furthermore, his design would eliminate the image-rotation issues and pronounced driving clock errors of the horizontal heliograph. As it turned out, his reasoning stood the test of time.

In 1908 Campbell (1908a; 1908c) published his thoughts on the advantages of Schaeberle's design. A lens, with its tube assembly mounted well above the ground, is easily ventilated and will be subjected to far less image-degrading ground heat-radiation. Schaeberle's Camera's components could be rigidly fixed in place and be independent of each other, thereby ensuring that any vibrations from the tube section would not transmit to the lens or plate holder. Schaeberle (1895) realized that "Any advantage due to the large scale given by a telescope 40-feet long will, in a great measure, be lost unless great stability of the image on the photographic plate is secured."

To test the feasibility of his concept, Schaeberle placed the Clark & Sons lens from the Observatory's horizontal photoheliograph in the slit of the meridian circle room. From star trail tests, the best focus was found to be at 40 feet and 1.2 inches (Schaeberle, 1895).

The original version of the new 'Schaeberle Camera' was assembled on Mt. Hamilton in the autumn of 1892. The Camera's length was kept near the sloping ground with its lens supported on an inclined plank-tripod. The moving plate carriage system was mounted on its own pier. The Camera's tube was made of black painted canvas which was attached to a wooden framework with cord via iron rings. The support for the tube frame consisted of wooden posts that were placed vertically in pairs at intervals up the sloping hillside. The rigid wooden tube frame was secured to the posts. A canvas tent covered the plate area. The Camera survived several stormy days and produced good test exposures of star fields and the Moon. The ability to change plates quickly was tested and found to be satisfactory (ibid.).

4.1 The Camera's Unique Moving Plate-Holder System

Schaeberle (ibid.) designed a moving plate-holder (Figure 4) that would follow the diurnal motion of the Sun and keep the Sun's image centered on the photographic plate. He assembled a quadrilateral iron-frame track guide to accept a wheeled triangular-shaped plate holder. The plate holder traveled on three carefully-made wheels on tracks whose surfaces were machined as smooth as possible. The lower wheels had knife-edges that followed a V groove cut into the face of the iron frame work.

Schaeberle then devised a procedure for setting the correct plate velocity for diurnal motion. The linear motion was obtained by using the Sun's hourly motion from the Ephemeris on the date and time of the eclipse. This hourly motion, along with the focal length of the Camera, was used to compute the distance that the Sun's image would travel on a stationary photographic plate. The clock mechanism—linked to one of the chronometers—governed the rate of motion. Schaeberle (1895) described the adjustment of the clock:

> The lateral motion (diurnal) was given to the plate by the unwinding of a strong, flexible wire wound around a drum mounted on the clock's winding axis. The size of this drum was determined by computation, and the final adjustment of the velocity was then made by shifting the balls of the centrifugal governor.

Final adjustments were made by observing stellar images at the negative's plane for movement. Then long exposure plates of stellar sources were made and inspected for any residual motion in the stars' positions.

By the time of the 1896 and 1898 eclipses, Schaeberle and Campbell had revised and refined the components, alignment and focusing procedures of the Camera. Campbell provided a description of the revised Camera's parts and the method used for optical alignment in a letter written to Ormond Stone in 1899.

Figure 4: The original plate-holder and drive clock as it appeared at the December 1889 eclipse site (Mary Lea Shane Archives).

The objective lens and the plate-holder were mounted on the tube and aligned with the optics of the 36-inch refractor. The plate-holder could be tilted 45º. The lens was carefully collimated using a candle flame at night. The plate-holder was then tilted until the candle flame and its reflections from the lens elements were all in one straight line. On a warm night, the telescope was directed towards some bright stars at the same altitude and azimuth as the upcoming eclipse, and the stars were allowed to trail across a photographic plate twice while the declination of the plate holder was varied slightly on each occasion. The plate-holder was then set for best focus. On future eclipses, the pictures were found to be beautifully sharp (Campbell, 1899).

The Camera's moving plate-holder was constructed by a machinist under daily supervision. According to Campbell, no shop drawings were made nor computations kept of the plate-holder's construction, but in his letter to Stone, Campbell (ibid.) created detailed drawings and descriptions of parts of the photographic plate system (see Figures 5 and 6).

In his letter to Stone, Campbell (ibid.) also describes how the plate-holder worked:

> As the Sun moves up and southward during the eclipse, in a curved diurnal path, the plate-holder must move downwards and to the north, in a slightly curved path which is concave to the southward. The plate carriage travels on five wheels that are about 1.5 inches in diameter. The one wheel on the northern edge and two wheels on the southern edge simply bear the carriage up from the supporting track. The other two wheels on the

southern side guide the carriage along the curved side of the track.

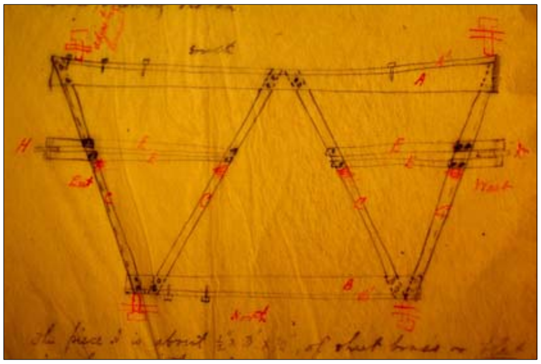

Figure 5: Plate carriage track drawing showing the arrangement of the curved wheel guides (Campbell Copy Book – Mary Lea Shane Archives).

The plate carriage consisted of a skeletal frame that was firmly attached to a top plate of sheet to avoid flexure in the assembly. Two holes were cut in the plate for the camera-operator's hands to handle the plate boxes. The metal track assembly was attached to a strong wooden framework. Adjusting screws allowed fine calibration of the diurnal motion. To finally bring the plate into delicate focus, the lens could be moved in or out and then recollimated.

The original cardboard photographic plate-holder boxes were subsequently replaced with thin wooden boxes with removable lids. Each plate box lid would serve as the Camera's shutter. A plate-holder would be secured in place on the plate carriage by metal stops, forming a three-point support system to float the plate-holder above the top of the plate carriage.

4.2 The Revised Tube and Support Structure

The original wood tube frame was replaced with a 0.5-inch iron pipe frame. The new tube was made of an exterior white duck cloth cover and lined on the inside with two thicknesses of black muskin. Campbell (ibid.) noted that "Black outside absorbs the heat which is extremely objectionable." This cover was fitted with iron rings along its length in order to secure it to the pipe frame.

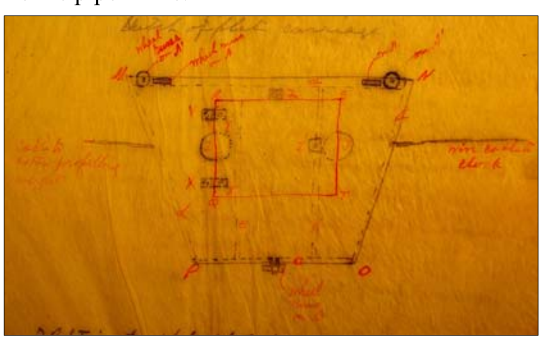

Figure 6: Plate carriage drawing showing the top plate overlay on the skeletal frame; the position of the plate-holder is marked in red (Campbell Copy Book – Mary Lea Shane Archives).

At the 1898 eclipse in India, Campbell erected an independent two-tower system to support the objective lens and the tube. The towers were isolated from each other so that any tube motion due to wind would not affect the objective lens. Tower materials were obtained on site until 1905 and then became part of the cargo manifest at subsequent eclipse expeditions. According to Campbell (ibid.), an excavated pit for the plate system was needed, "… if there should be a wind storm, of some violence within a few days before the eclipse, the tent on level ground might be blown down and smash the final adjustments."

4.3 The Objective Lenses

The primary objective lens used for expeditions was the Alvan Clark & Sons 5-inch aperture lens from the Observatory's horizontal photoheliograph that was installed on Mt. Hamilton by D.P. Todd for the 1882 transit of Venus. This lens had been especially figured for solar photography, and Holden (1892; 1895) wished to retain it at the LO for ongoing projects.

In 1895, Holden commissioned J.A. Brashear to make a 6-inch aperture lens of the same focal length, and this was delivered to the Observatory in March of 1896 (Brashear, 1895). Unbeknownst to the Lick astronomers, problems with this lens were to persist for many years, and they were never fully resolved. The ensuing interaction between the astronomers and Brashear would consume countless hours of time and energy that could have been used more profitably for research. Upon testing the lens the astronomers found its focal length was too short, and it was promptly returned to Brashear for correction. He responded (Brashear, 1896):

> According to our measures the objective was a very little short but we had no idea that you demanded such an accuracy in focal length … as 1/20,000″ in the versed sign of any of the curves will make as great a difference as you indicate in your letter [of 17 April].

As it turned out, Brashear's tape measure was defective (ibid.). The lens was star-tested on the evening of 5 August 1897 and found to have very bright triangular ghost images. Campbell (1897b) declared that "The lens is not right, I cannot waste any more time with it, and cannot wait to have it returned to Brashear." For his part, Brashear (1897) thought that the problems were due to unequal separation of the lens elements which could produce the 'triangle' ghost images. Brashear elaborated: "We feel so certain that the lenses were worked correctly and that the glass is all right ... I beg you to understand we are making no excuse for the lens in any way, shape or form." Schaeberle (1897) had his own ideas about the problem with the lens and informed Brashear that

> The trouble seems to be due to the very fact that the two surfaces (inner) have the same radius of curvature, so that by double reflection from their practically parallel surfaces the reflected rays being parallel to the direct rays (or nearly so) come to a focus in the same plane in the the (sic) principle image. [His underlining].

Campbell finally decided not to use the lens, and it would remain in storage until the eclipse of 1918.

A 4-inch, 40-foot focal length lens was also made by Brashear at Holden's request, and was taken as a back-up lens on the 1893 eclipse expedition. Brashear (1891) forwarded Holden his and Hastings' comments regarding this lens:

> Neither Dr. Hastings nor I can see how you will use it, or what use it will be after it is made, as it will in practically be identical with pin hole photography and of no value in your work.

Perhaps the idea of this lens emerged when Holden learnt of Harvard College Observatory's futile attempts to photograph the 1886 eclipse with a 4-inch horizontal heliograph of 38.5-feet focal length (Baily, 1931).

4.4 Image Sizes of the Observatory's Photographic Lenses

Table 1 lists the range of cameras that traveled with the LO on its various eclipse expeditions. The lunar disk image scale can be seen to increase by a factor of 9 from the half inch image produced by Barnard's water reservoir telescope in 1889 to the 4.5 inch images produced by the Schaeberle Camera from 1893.

5 A BRIEF ACCOUNT OF THE SCHAEBERLE CAMERA ON THE DIFFERENT SOLAR ECLIPSE EXPEDITIONS

Table 2 lists the eclipse years, site location, duration of totality, altitude of the eclipsed Sun, plate types and sizes for the Schaeberle Camera, and exposures used.

5.1 Mina Bronces, Chile: 16 April 1893

This eclipse presented the first opportunity to use the Camera under actual field conditions (see Figure 7). Schaeberle, alone, represented the Observatory, and he secured volunteers en route and at the mining camp reached by rail and rough wagon road (Schaeberle, 1895).

Precise positional coordinates were obtained from repeated sextant readings at the eclipse site along the eclipse path, and these were used to align the supports for the Camera (ibid.). The chronometer was calibrated at the port and transported to the eclipse site. In positioning the Camera, Schaeberle (ibid.) admitted, "I confess to having asked myself several times, Will the sun's image fall centrally upon the photographic plate at the critical moment?"

Assembly and stabilization of the Camera were accomplished with the utmost care by Schaeberle (Eddy, 1971). The upper end of the slope was excavated two feet deep into broken rock for the lens pier. A three foot pit was excavated into broken rock for the plate holder. The track and plate carriage framework were securely fastened to the ground with a liberal supply of mortar. Guy wires were rigged to the top of all supporting frame posts and anchored firmly to the ground with iron pins. A curtain was attached to the front end of the Camera for wind protection. The ground within the plate area tent was covered in a plaster 'barro' to prevent dust. The lens was positioned very close to the tube material to minimize any stray light leakage into the interior of the tube. Another light trap was arranged by sewing a piece of black fabric on the front of the tube immediately before the lens mount, with a hole left for the lens. A cardboard partition, with a hole, was placed one foot in front of the lens to block off-axis light (Schaeberle, 1895).

In order to collimate the objective lens with the plate-holder, a plane mirror was placed at the slide-holder. The slide plane was collimated by reflecting lantern light from an observer at the top end back to the observer looking down the optical axis and adjusting the plate-holder as necessary. The lens was then collimated in the same manner as for the plate-holder by reversing the positions of the plane mirror and the observer respectively. The final alignment was accomplished by using an eyepiece at the focal plane to view stellar images and after that by exposing a plate at night to record star images (ibid.).

At the time of the eclipse, Schaeberle (ibid.) alone operated the Camera. He commanded the start of all the eclipse instruments whilst viewing the large image present on the plate-holder. Volunteer J.J. Aubertin exclaimed, "God's picture … one grand, overwhelming figure is the symmetrical corona, of a deep, circular margin extending all around into valance or festoons of lovely texture."

The excellent plates, which were developed at the site, revealed prominences and fine detail in the solar corona. Schaeberle (ibid.) declared that the results were a further verification of his coronal theory.

5.2 Akkenshi, Japan: 8 August 1896

Schaeberle traveled to Japan with the Camera for this eclipse, and the program was to be fully photographic in nature with a range of cameras with different apertures and focal lengths. However, the sky was completely covered by clouds and the eclipse was not observed (Campbell, 1894; Holden, 1896).

5.3 Jeur, India: 22 January 1898

For the 1898 Crocker Eclipse Expedition to Jeur, India, a program of coronal photography and coronal spectral studies was planned. A change to another site nearby became necessary due to an outbreak of bubonic plague. The new location lacked a suitable hillside to support the Camera, so W.W. Campbell set forth and constructed two towers to raise the lens and tube of the Camera to an altitude of nearly 51° (see Figure 8). Campbell did most of the work himself after he fired the local lead worker. Mrs Campbell (1898) noted in her diary:

Table 1: Cameras used in the LO direct coronal photography program, eclipse year first used, and their basic optical specifications.

Photographic Instrument	Year First Used	Clear Aperture (inches)	Focal Length (inches)	Focal Ratio (f/)	Image Size On Plate (inches)
Dallmeyer Portrait Lens Camera	1889	6.0	33	5.5	0.3
Clark Equatorial Refractor	1889	6.5	76	11.7	0.7
Barnard's Water Reservoir telescope	1889	2.0	49	24.5	0.5
Schaeberle's Newtonian	1889	18.0	150	8.3	1.4
Schaeberle 40-foot Camera	1893	5.0	482	96.4	4.5
Schaeberle 40-foot Camera	1893	4.0	482	120.5	4.4
Regular "instantaneous" Camera	1898	1.4	11	7.8	0.1
Floyd Camera-Willard Lens	1898	5.0	68	13.6	0.6
Schaeberle 40-foot Camera	1918	6.0	482	80.3	4.5

Table 2: Eclipse dates and LO eclipse site locations, Schaeberle Camera plate emulsion type, plate sizes, and exposure times.

Year	Site	2nd-3rd Contact (m. s.)	Solar Altitude (°)	Plate Type	Plate Size (inches)	Exposures (seconds)
1893	Mina Bronces, Chile	2 51		Seed 26	18x22	½,2,4,8,16,32,24,1/4
1896	Akkeshi, Japan				18x22	Clouds
1898	Jeur, India	1 59.5	51		14x17	
1900	Thomaston, Georgia, USA	1 30				
1901	Padang, Sumatra	6 09		Seed 27	18x22, 14x17 8x10	½,1,2,4,16,40,150,4, 25,8,1,1/2
1905 1905 1905	Alhama, Spain Aswan, Egypt Cartwright, Labrador	3 45 2 26 2 30	55	Seed 27 Seed 27 Seed 27	18x 22, 14x17 18x22, 14x17 18x22, 14x17	½,1,4,8,64,32,24,¼ ½,1,4,8,64,32,24,¼ Clouds
1908	Flint Island, Pacific Ocean	4 06	74	Seed 27		4,2,32,16,64,32
1914	Brovarỳ, Russia				14x17	Clouds
1918	Goldendale, Washington, USA	1 57.4	45	Seed 30 Process		1/4,4,8,32,¼, + 5 not listed
1922	Wallal, Australia	5 15.5	58			Range from ¼ to 64
1923	Ensenada, Baja California, Mexico	3 34		Seed 30 Process	14x17 8x10	Clouds

Figure 7: The Schaeberle Camera mounted on the hillside in Chile. Schaeberle is standing centre right with his outstretched hand on the framework (Mary Lea Shane Archives).

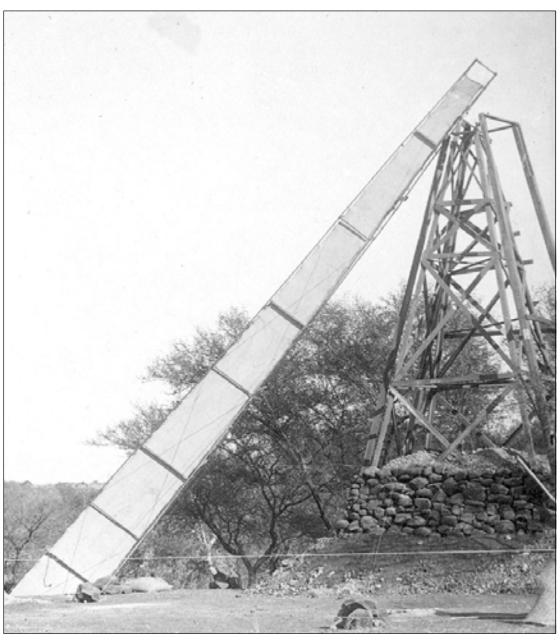

Figure 8: The two towers of the Schaeberle Camera and the rock wall at Jeur (India), with overall height lowered by use of a pit for the plate-holder (Mary Lea Shane Archives).

> He is working from before dawn till after the sun has left the sky. Stones that four men cannot move he lifts with ease. And he is never tired!

The tube end of the Camera was held in place by iron pins driven into the ground, and the tube was then anchored with a system of duplicate wire cables. A nine foot rock wall anchored the bottom of the tower. The day before the eclipse, Campbell (1898) discovered that the guiding tracks and clock had been bumped or tampered with by an unknown person or animal, so he made sure that the camp was well guarded that evening.

On eclipse day the plates made with the Camera were considered excellent and "… as expected …" by Campbell (ibid.). A unique feature on the plates was the presence of coronal streamers, with streamer hoods inclosing the prominences (ibid.). Campbell (ibid.) also remarked that "It is plain that no astronomer was ever more assisted by volunteer observers."

5.4 Thomaston, Georgia, USA: 28 May 1900

On short notice, the LO assembled a Crocker Eclipse Expedition for the May 1900 eclipse, which was visible from the USA; this was attended by W.W. Campbell and C.D. Perrine. The program consisted of cameras for direct coronal photography and a range of spectrographs for chromospheric and coronal studies. For the first time, the LO arranged for time signals to be sent directly by telegraph wires from the United States Naval Observatory (USNO) to the chronograph at the eclipse site. This enabled the astronomers to obtain a precise set of location coordinates for the site (Campbell and Perrine, 1900).

The astronomers were popular with the locals, with the notable exception of the landlord of the eclipse site location whom Campbell (1900a) referred to as a 'terror'. However, the quality of the local food was poor and Perrine became seriously ill, although he did manage to perform his duties on the day of the eclipse.

The plates obtained with the Schaeberle Camera were of good quality, which could not be said for plates taken by other expeditions sited along the eclipse path. In fact, the results from the other parties were so poor that Campbell commented that there seemed to have been a 'hoodo' on this eclipse.

Accordingly, the local people and the Lick Observatory party wasted no time in promoting their success. Campbell also came to the rescue of O. Stone from South Carolina who did not know how to process his plates (Campbell, 1900a; 1900b; 1900c; 1900d; Campbell and Perrine, 1900).

5.5 Padang, Indonesia: 17-18 May 1901

The 1901 Crocker Eclipse Expedition to Padang, in Sumatra, came upon the heels of the death of the late Director of the Observatory, J.E. Keeler. C.F. Crocker had also passed on, but his brother, W.H. Crocker, agreed to fund this expedition and future LO eclipse expeditions. The long duration of totality and the high altitude of the Sun provided ideal conditions for coronal observations. LO staff had one month to make preparations prior to departure, and the voyage out to Sumatra then took seven weeks (Perrine, 1901a; 1901b). In addition to the regular program of direct coronal photography and the making of spectrograms of the solar surface and corona, a search for intra-Mercurial planets was planned (Perrine, 1901b).

The expedition was led by C.D. Perrine, who selected fifteen volunteers to assemble the camp and to man the instruments on the day of the eclipse. Perrine soon faced his first substantial problem at the site when local religious leaders prophesied that the expedition had caused an epidemic in the nearby town of Kampong and threatened to attack the camp. Luckily this did not eventuate (Perrine, 1901b).

The Camera's towers had to be thirty six feet high, (Figure 9), as a pit area could not be dug. The inner and outer towers were constructed of bamboo and covered with thatch. On eclipse day the viewers saw a great comet at totality, while the exposed solar plates revealed valuable coronal detail:

> … clouds of coronal matter were piled up as if by an explosion of the Sun's Surface … The disturbed area appeared to have its origin … near a compact prominence, and masses of matter are shown radiating from it in almost all directions … The whole area resembles the condensations seen in photographs of the *Orion* and other irregular nebulae (Perrine, 1901b).

Perrine was convinced that the observed events demonstrated that the corona is directly linked with other solar phenomena, all needing a concise explanation. Perrine (1901a) summarized the observations with these comments: "The greatest enthusiasm was manifested by all in the preliminary rehearsals as well as in the observations on eclipse day".

5.6 Labrador, Spain and Egypt: 30 August 1905

The Lick Observatory sent expeditions to Labrador, Spain and Egypt to observe the August 1905 eclipse. Parties equipped with Schaeberle type tower cameras were sent to locations separated 2.5 hours apart on the eclipse path in the hope that plates from different sites would yield answers to questions concerning changes in the fine detail within the corona over time.

At Cartwright, a Hudson Bay Company post in Labrador, the expedition under the direction of H.D. Curtis established camp. Only direct coronal photography and an intra-Mercurial planet search would be conducted. The expedition's personnel were subjected to vicious biting flies and hoards of mosquitoes, and a fierce gale arrived and threatened the towers of the 40-foot camera. On the vital day no results were obtained owing to the dense clouds (Curtis, 1905; Campbell, 1904; 1905).

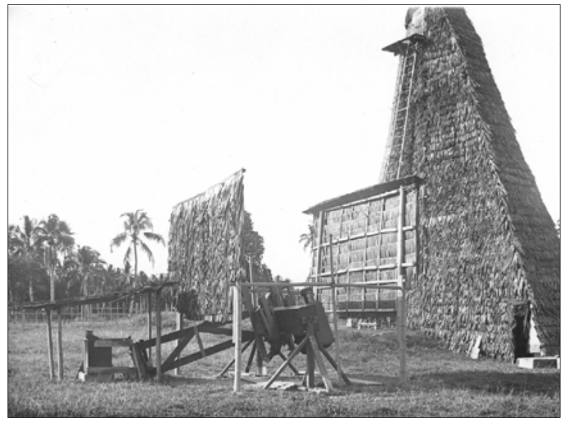

Figure 9: The thatch-covered bamboo towers of the Camera in Sumatra. A flip-top cover protected the other cameras and the spectrograph in the foreground (Mary Lea Shane Archives).

W.J. Hussey led the Egyptian contingent, and they set up camp on the bank of the Nile River at Aswan (Figure 10). Hussey, who received a great deal of assistance from the Egyptian Government, was joined by H.H. Turner from Oxford University. Direct coronal photography, an intra-Mercurial planet search and a single spectrogram of the general spectrum of the corona made up the program. The 40-foot camera was equipped with a 5-inch lens obtained from the USNO (Hussey, 1906; Campbell, 1904). After the eclipse, the plates were safely secured for shipment back to Mt. Hamilton.

The third expedition, to Alhama in Spain, was led by Campbell, who used a series of maps provided by the Madrid Observatory to settle on the location of the observing site. According to Campbell and Perrine (1906), their volunteers consisted of a group of academic professionals who successfully undertook the exceedingly strenuous task of setting up the eclipse instruments, often working in the rain. The original Schaeberle Camera was raised to an elevation of 55° (Figure 11). On eclipse day, the spectrographs were started late as totality began eighteen seconds earlier than anticipated, but excellent plates revealed coronal streamers out to one solar diameter. Upon subsequent examination, the prominences and coronal features were found to be highly structured (ibid.).

Figure 10: The 40-foot Schaeberle Camera on the bank of the Nile in Egypt (Mary Lea Shane Archives).

Figure 11: The Schaeberle Camera at the Alhama eclipse camp in Spain (Mary Lea Shane Archives).

5.7 Flint Island, Pacific Ocean: 3 January 1908

Flint Island, a member of the Line Islands, is a narrow almost inaccessible Pacific atoll, and was selected as the only suitable site for the January 1908 Crocker Eclipse Expedition. It was a logistical challenge getting there and then landing the thirty-five tons of equipment though the rough surf. Campbell's party was joined at the last minute by the Smithsonian Institution, a USNO representative and E.P. Lewis of University of California at Berkeley (Campbell, et al. 1908). Another eclipse party, from Sydney (Australia) and Auckland (New Zealand) also used Flint Island as their observing base. All of the visitors were greeted by biting flies, mosquitoes and giant turtles (e.g. see Figure 12).

A rather ambitious science program included direct coronal photography, a search for intra-Mercurial planets, coronal photometric and polarization studies and a range of spectrographic studies (Campbell, 1908b; 1908c; Campbell et al. 1908; Perrine, 1908; 1909). This was to be the first time that heat radiation from corona studies would be measured on a LO expedition, by guest astronomer C.G. Abbot (1909).

Figure 12: Mrs Campbell posed for her portrait on a giant turtle during the Flint Island expedition (Mary Lea Shane Archives).

Lumber for the Camera's towers was shipped from San Francisco and erected on site, and a 15-inch pit was dug for the plate-holder (Figure 13). Although it rained right up to the moment of totality, a hole then appeared in the clouds and the tarp over the objective lens was quickly uncovered and the eclipse was photographed (Campbell and Albrecht, 1908). The resultant plates were considered excellent, and coronal streamers were recorded out to two solar diameters (ibid.). Campbell (1908b) also observed a particular coronal feature:

> There was a conspicuous conical pencil of radiating streamers [see Figure 14] … whose vortex, if on the sun's surface, would be within the largest sunspot group visible on June 3.

Figure 13: The Schaeberle Camera among the palm trees on Flint Island (May Lea Shane Archives).

5.8 Brovarỳ, Imperial Russia: 20 August 1914

The 1914 Crocker Eclipse Expedition to Brovarỳ in Imperial Russia would become an adventure for the unsuspecting LO group. P.A. Hearst joined Crocker in funding a "… powerful equipped expedition …" which was led by Campbell and H.D. Curtis. The expedition would conduct the same range of coronal studies that was carried out at previous eclipses and would focus on direct photography of star fields in the region of the Sun in order to investigate Einstein's Theory of Relativity. Cameras used for the previous intra-Mercurial planet search were refined for this purpose. Camp life (Figure 15) was described by Campbell and Curtis (1914) as pleasant and delightful.

Unfortunately the eclipse was clouded out, and the LO party then found itself isolated in a Russia that was by now caught up in a national revolution *and* World

War I. Expedition members were forced to flee the war zone and to leave all of their instruments behind. Eventually the equipment found its way to the National Observatory at Pulkowa, and it would remain there for the next four years (ibid.).

5.9 Goldendale, Washington, USA: 8 June 1918

When it was realized that the equipment left in Russia would not arrive back in the USA in time for the June 1918 Crocker Eclipse Expedition to Goldendale (Washington state), instruments were hastily assembled from spare and borrowed components. Its defects forgotten, the old 6-inch Brashear lens was even used in a 40-foot camera (Campbell, 1918a; 1918b). The expedition was under the command of W.W. Campbell, and established itself by invitation on the grounds of the Morgan Estate. Local lumber was acquired to build the towers for the 40-foot camera.

It was cloudy on eclipse day, except for the moment of totality when a hole in the clouds miraculously opened up. Campbell was at the Camera and was so surprised by the number of brilliant points of light caused by surface variations on the Moon that he almost delayed giving the 'Go' command to the expedition members. In the event, the defective lens produced ghosts, which were visible on the processed plates, but Campbell (1918b) noted that "The scientific values of the plates were not reduced in any way." in that they revealed remarkable sheaths of streamers and large prominences covered by hoods of curved streamers. According to Campbell, (ibid.) during totality the atmosphere was tranquil and seeing conditions were magnificent.

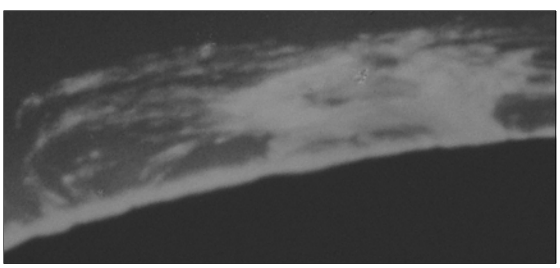

Figure 14: A large quiescent prominence captured on a Schaeberle Camera plate (Mary Lea Shane Archives).

This would be the LO's second chance to secure plates for the verification of the Einstein effect, and the same plates would be used for a continued intra-Mercurial planet search that was all but abandoned by Campbell after the 1908 eclipse (Campbell, 1908a; Curtis, 1919). While the resultant plates were of good quality, it was questionable whether they provided the accuracy needed to validate the Einstein effect (Campbell, 1922b; 1923).

5.10 Wallal, Australia: 21 September 1922

With a high level of support from the Australian Government, Campbell mounted the September 1922 Crocker Eclipse Expedition to Wallal in Western, Australia. Wallal was a sheep and telegraph station situated along Ninety Mile Beach (Figure 16), on the northwestern shores of the Australia continent (Campbell, 1923). The nearby Perth Observatory party, under their Director, Curlewis, would accurately determine the coordinates of the LO position for time-keeping purposes (ibid.). A full complement of instruments would make the trip, in order to continue the coronal studies that had been conducted at previous eclipses. Again, emphasis was placed on the Einstein effect as there seemed to be some continuing doubt about the 1919 eclipse results obtained by Eddington's party (e.g. see Jeffery et al., 1989).

Figure 15: The eclipse instruments at Brovarỳ in Russia (Mary Lea Shane Archives).

The goal of the coronal program for the Schaeberle Camera, now home from Russia, was to secure images for photometric studies of the brightness of the corona. In addition, a search for coronal structure motion would be made by comparing the Wallal plates with those taken with a borrowed LO 40-foot camera by an Adelaide party located at Cordillo Downs, thirty-five minutes away. The plates of the partial phases would be used in the determination of the relative positions of the Sun and Moon (Campbell, 1922a; 1923). The cloth-covered towers of the camera (Figure 17) also provided additional shade for the sensitive Einstein cameras. As daytime temperatures soared, local Aborigines placed branches around the instruments to hold down ground-heat radiation and poured coarse sand to hold the fine dust down. On eclipse day, the Aborigines sprinkled water continuously to cool the surrounding ground (Campbell, 1923). C.E. Adams, the Government Astronomer of New Zealand, took the exposures with the Camera, and obtained excellent results (see Burman and Jeffery, 1990).

Figure 16: Unloading the eclipse freight on Ninety Mile Beach, Western Australia (Mary Lea Shane Archives).

5.11 Ensenada, Mexico: 10 September 1923

The September 1923 Crocker Eclipse Expedition to Ensenada, Mexico, was to be the last time that the LO would set up the Schaeberle Camera (Figure 18) in order to continue the "… systematic accumulation of observation material relating to eclipses of the Sun." (Wright, 1923). As luck would have it, this eclipse was clouded out.

Figure 17: At Wallal, protective cloth covered the Schaeberle Camera and the Einstein camera (Mary Lea Shane Archives).

5.12 Camptonville, California, USA: 28 April 1930

The April 1930 Crocker Eclipse Expedition to Camptonville, California, proved unusual in that totality would be last a mere 1.5 seconds, so the Schaeberle Camera could not be used. LO Director, R.G. Aitken, decided to set up three stations across the predicted width of the umbral shadow just in case the site position calculations were incorrect, but the computations turned out to be very accurate (Aitken, 1930; Moore, 1930).

5.13 Fryeburg, Maine, USA: 31 August 1932

For the August 1932 Crocker Eclipse Expedition to Fryeburg in Maine, Aitken selected J.H. Moore to conduct a program that would continue the systematic accumulation of observations of the solar corona and chromosphere. A refined group of moving-plate and jumping-film spectrographs was meant to record chromospheric and coronal spectra.

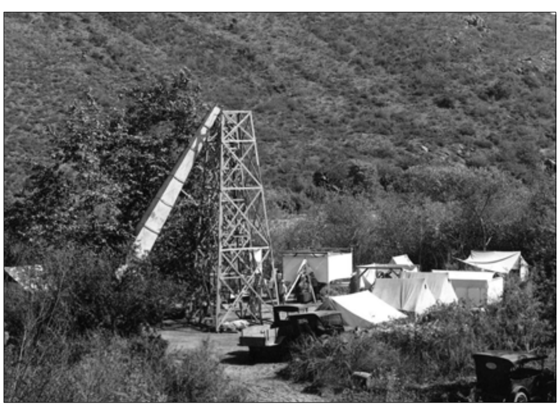

Figure 18: The eclipse camp in Ensenada, Mexico (Mary Lea Shane Archives).

Direct coronal photography would continue, however, without the Schaeberle Camera. W.H. Wright and Aitken determined that the corona images obtained with the 5-foot and 15-foot Einstein cameras were of sufficient quality to make use of the 40-foot Camera unnecessary. Photographic emulsions were now fine grained permitting large scale enlargements to be made (Wright, 1932).

The Schaeberle Camera was eventually transferred to the University of Michigan and was used under the direction of H.D. Curtis, a former employee of the Lick Observatory (see Eddy, 1971).

6 DISCUSSION

6.1 Fate of the Mechanical Theory of the Solar Corona

The Schaeberle 40-ft Camera was the mainstay of the Lick Observatory solar eclipse program for thirty years and provided a succession of excellent photographs of the solar corona, but what of the theory that inspired it?

As soon as the 40-ft Camera was operational Schaeberle used photographs obtained with it to evaluate his theory. Upon examining images of the 1893 eclipse, he discovered that his theory needed to be developed further as his initial work only pertained to the ideal case of streamers uniformly distributed in sunspot zones (Schaeberle, 1893). Unfortunately, these ideal occurrences were found to be the exception. Schaeberle (ibid.) described structure in the equatorial regions which had the appearance of two opposite magnetic poles on the Sun's equator, but still defined by gravitational forces.

After the appearance of the Lick Observatory's report on the 1893 eclipse (Schaeberle, 1895), no further publications by Schaeberle about his mechanical theory appeared in print, with one minor exception. In an article submitted to the *San Francisco Examiner* newspaper on 19 April 1898, Schaeberle confirmed his 1893 claims:

> All the evidence given by the prominences leads to the conclusion that this matter is in rapid motion and that instead of rising from the sun's surface in irregular masses, the structure is just as definite as is found to be the case in the coronal streamers. In other words, every prominence and protuberance visible during this eclipse was made of individual streams of matter apparently moving in elliptical orbit with the sun's center as their foci. The almost certain conclusion appears to be that all prominences are of the same general structure. (Schaeberle, 1898).

At Campbell's invitation, J.A. Miller visited the Lick Observatory during the summer of 1909, and accessed the plates obtained during the 1893 through 1905 eclipses, in order to evaluate Schaeberle's theory. Whilst agreeing in principle with many of the points made by Schaeberle, he begged to differ on at least a couple of points. For instance, he suggested that radiant pressure generated by disturbances may play a part in explaining Schaeberle's observations (Miller, 1911).

A little later, W.W. Campbell (1918c) wrote that coronal matter could be transported by volcanic force (as predicted by Schaeberle), radiation pressure, or a combination of these and other unknown forces. However, the arrangement of coronal matter in well-defined streamers may result from the Sun's magnetic properties, as predicted by Bigelow and others who felt that local magnetic fields were in control.

Surprisingly, Campbell does not mention George Ellery Hale's work at Mt. Wilson Observatory, and specifically his 1908 discovery of the Zeeman splitting of spectral lines associated with sunspots. It was primarily the research conducted by Hale that sounded the death-knell for Schaeberle's mechanical theory of the solar corona, and it is relevant to point out that after the detection of Zeeman splitting the Schaeberle Camera was only used successfully for two further eclipses (in 1918 and 1922).

6.2 The Scientific Contribution of the 40-ft Camera: An Introductory Note

Excellent photographs of coronal form and structure were obtained with the Schaeberle Camera on many of the Lick Observatory expeditions (e.g. see Figures 19 and 20), and sometimes these were combined with spectral and polarization data obtained with other LO equipment.

The specific role that the Schaeberle Camera played in the overall Lick Observatory solar research program will form part of another paper, so we will not discuss it here other than to highlight three particularly note-worthy accomplishments:

1. A contour map of the solar corona was generated from photographs taken during the 1893 eclipse, and this was then compared with maps made during the two 1889 eclipses (Schaeberle, 1895).

2. Studies of precise coronal brightness were highly suspect up to and including the 1905 eclipses, because of problems with the stability of the Carcel standard lamp that was used to calibrate the photographic plates (Osterbrock, et al., 1988). This problem was then solved and during the 1905 and 1908 eclipses standardized plates were used with the Schaeberle Camera to determine the levels of intrinsic actinic light in different regions of the solar corona (Perrine, 1908). Later these measurements were compared from eclipse to eclipse.

3. Plates obtained during the 1922 Wallal eclipse were used in the search for coronal motion. These same plates were later examined by J.A. Eddy and J. Goff (1971) when preparing their atlas of the white light corona, and they were again used when Eddy (1973) was researching evidence for a neutral sheet within the corona.

Finally, it is interesting to note that at no time did any of the LO staff use coronal features displayed on the Schaeberle Camera plates to investigate magnetic models of the solar corona.

7 CONCLUDING REMARKS

It was the merging of the highly regarded talents of three men that successfully launched the acclaimed direct photography program of the LO eclipse expeditions. E.E. Barnard came to the Observatory as a skilled photographer, S.W. Burnham was a photographic emulsion and processing expert and J.M. Schaeberle was a skilled telescope-maker with a background in optical theory. The three of them made for a powerful team.

From its inception, the Schaeberle Camera, with its novel moving plate-holder, produced fine eclipse images of large size and continued to produce outstanding plates until taken out of service at the LO after eleven expeditions. Other institutions would build similar cameras modeled after the Schaeberle Camera and achieve equally good results.

Figure 19: Schaeberle Camera photograph of the 1893 solar eclipse (Mary Lea Shane Archives).

The LO solar eclipse expeditions can be considered a bold adventurous project for a young cash-strapped institution. An eclipse expedition to a distant country, in the late nineteenth century, was a non-trivial challenge. The Schaeberle Camera and other instruments had to be readied and tested at home, with some indication that the observations would yield the intended research results. Permissions were required in advance for the transport of equipment and personnel through foreign lands. The transportation of fragile instruments by ship, rail and wagon—often under rough conditions—was always charged with at a high-level of risk. The establishment of an eclipse station, where staff and volunteers would live for some time, needed careful thought and planning. Then, during those brief moments of totality, the weather needed to cooperate, observers needed to successfully perform their assigned tasks on time, and the Schaeberle Camera and other instruments needed to function as designed. There were also other unforeseen issues that one could not prepare for but which had to be resolved.

Figure 20: Schaeberle Camera photograph of the 1898 solar eclipse (Mary Lea Shane Archives).

Although the Lick Observatory's ambitious 40-year solar eclipse program was a resounding success in that the Crocker Expeditions provided invaluable new information on prominences and the corona, Moore was moved to point out in 1933 that in spite of these achievements it still was not possible to adequately explain all observed coronal phenomena. Clearly a means of successfully viewing the solar corona outside of eclipse were called for, and with the advent of the coronagraph this became a reality.

8 NOTES

1. This January 1889 solar eclipse launched the Lick Observatory's coronal science research program. J.E. Keeler began by repeating the observations of C.S. Hastings who, in 1883, had theorized that the light of the corona was a diffraction effect caused by the Moon (Holden, 1889c). Keeler's observations were considered as further proof that Hastings was wrong. At the same time Holden et al (1889) suggested that branching coronal forms were due largely to the presence of streams of meteorites drawn in towards the Sun.

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